E/CONF.39/A/98
10 Oct.1962
ORIGINAL : ENGLISH

UNITED NATIONS CONFERENCE
ON THE APPLICATION OF SCIENCE AND TECHNOLOGY
FOR THE BENEFIT OF THE LESS DEVELOPED AREAS

Agenda Item: A. 2

Japan

ALLOCATION OF STORAGE CAPACITY OF A RESERVOIR FOR MULTI-PURPOSE USE

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ALLOCATION OF STORAGE CAPACITY OF A RESERVOIR FOR MULTI-PURPOSE USE

by

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I. HISTORY OF JAPAN'S MULTI-PURPOSE DAM PROJECTS

1. The history of multi-purpose dam projects in Japan dates back about forty years. In 1923, Dr. Mononobe, the then Director of the Public Works Laboratory of the Ministry of Home Affairs, submitted to the Government an opinion that rivers should be developed on a comprehensive basis. The main points contained therein are as follows:

(a) Since the vast river channel resulting from river improvement can demonstrate its full capacity for only a very short period, it is felt that controlling the river discharge by storage of water would be more advantageous for flood control.

(b) One of the climatic characteristics of Japan is that in winter there is a dearth of water, which decreases the output of water-power generation. Since there are no floods during this season, the capacity allocated for flood control may be utilized for power generation.

(c) In view of the fact that, generally speaking, there are not many suitable reservoir sites in our country, it is desirable to make their use multi-purpose.

(d) As a measure to prevent reservoirs from becoming filled up with sand, erosion control works must be carried out on more extensive scales.

(e) If a plan is developed to suit only the convenience of power generation, it may cause harm to other uses of the river, so a plan should be worked out by persons who are well acquainted with every aspect of the river.

2. In short, it was stated that since Japan's feasible reservoir sites were limited in number, being subject to various conditions such as the topography, geology, compensation, etc., she must develop her river systems in a manner most advantageous for flood control and water utilization after making investigations relative to the anticipated flood-control and water-utilization effects of the development projects.

3. Based on this opinion, requests were submitted starting in 1926 for budgetary appropriations needed to carry out investigations on the control of river water. However, it was only in 1937 that such appropriation was approved for the first time. Its breakdown was: 250,000 yen to the Ministry of Communications and 100,000 yen to the Ministry of Agriculture and Forestry.

4. The Ministry of Home Affairs undertook investigations for 67 rivers during the five year period from 1937 to 1941. With regard to these rivers, works were started successively upon completion of the respective investigations. The works of river control projects were started for 25 rivers prior to the Pacific War. Of these, only those for 11 rivers were completed. After the war, the projects suspended during the war were resumed, and also new investigations were undertaken. Of the investigations conducted from 1947 by the Economic Stabilization Board, with the cooperation of various Ministries, concerning development of 24 rivers, some were carried out by the Ministry of Construction. In addition, the Ministry of Construction was made responsible for conducting investigations

from an independent standpoint on rivers that had to be developed, to meet the requirements of the various purposes such as flood control, irrigation, power generation, etc. and for executing the projects.

II. COMPARISON OF CHARACTERISTICS BETWEEN PREWAR AND POSTWAR MULTI-PURPOSE DAM PROJECTS

5. The basic line of thinking in the planning of multi-purpose dams in the prewar days was to store in reservoirs the copious water of the season with much rainfall in summer and discharge it in the period of water shortage in winter to use it for power generation, irrigation and other purposes of water use.

6. The climatic conditions of Japan are different from those of the continent. There is no definite dry season or rainy season definable as such. What we call the rainy season is one in which there is a relatively large amount of rain and the dry season is one during which we have relatively little rain. Moreover, since the water courses of rivers are short, the longest being 200 km or so, the rain runs down to the sea in the course of a few days without feeding the underground stream to any notable extent, and changes of the discharge are very conspicuous. The ratios of the maximum discharges to the minimum discharges are shown in Table 1, from which can be seen the sharpness of changes in the discharge of Japanese rivers. Furthermore, droughts often extend over long periods

TABLE 1.

Country	Name of river	Ratio of max. to min. discharge
Japan	Tone	236
Japan	Chikugo	473
U.S.A.	Colorado	100
France	Seine	23
	Rhein	14
	Mekong	35
India	Ganga	35

TABLE 2. Unit: Million cubic meters

Country	Name of dam	Dam volume (A)	Storage capacity (B)	B/A
Japan	Sakuma	1.0	327	327
do	Narugo	0.2	54	270
U.S.A.	Hoover	3.4	38,400	11,400
India	Bhakra	3.9	4,300	1,100
Switzerland	Mauvoisin	2.0	160	80
Italy	Santa Guistina	0.1	172	1,720

of time. In checking the highest values of the continuous number of days without precipitation in the past years, we find that in not a few instances the value exceeds 50 days. Such being the case, it is extremely difficult to make the discharge of Japanese rivers constant.

7. Besides the meteorological conditions, there may be mentioned another important factor which makes it difficult to obtain constant river discharge —— viz. the fact that the capacity of reservoirs is small. As our country has steep topography, the storage capacity of a dam is very small even if it is constructed to be a high dam: such a dam is naturally very uneconomical, the storage capacity per cubic meter of concrete being only 200 - 500 cu m (Table 2). The availability of rivers' discharge can be increased by construction of dams. However, owing to the said meteorological and topographical disadvantages, it is necessary to construct a considerably large number of dams in order to really improve the availability of Japanese rivers. For reference, the relation between the storage capacity and the use percentage of the Tone and the Yodo, two typical rivers of this country, is given in the following table.

TABLE 3. Unit: 1,000,000,000 cubic meters

Condition	Natural	5 dams	Before development of Lake Biwa	After development
Total run-off	13		10	
Storage capacity	0	0.3	0.9	1.7
Total use tonnage	3.2	4.8	4.3	6.6
Storage cap./ Total runoff	0	2%	9%	17%
Use rate	29%	37%	43%	66%

8. Owing to such inefficiency of Japanese reservoirs, none of the multi-purpose dams constructed in the prewar years produce satisfactory results. This is especially the case as to their function of flood control. The author selected Okiura dam and Sagami dam as typical examples of multi-purpose dams projected in the prewar days and checked their flood control plans and the actual results thereof, the results being given in Table 4. The storage capacities are too small to achieve the expected results when floods occur. Considering that the

TABLE 4. Flood control

	Name of dam	
	Okiura	Sagami
Catchment area km^2	200.8	1016
Scheme included	F,A,P	F,P,A,W
Effective storage m^3	2,281,000	42,200,000
(Equivalent rainfall) mm	(11)	(42)
Design flood discharge m^3/sec	344	2,650
Regulated by m^3/sec	254	300
Annual power generation KWH	4,470,000	135,234,000

Actual Operation of flood control

Date	Sep.18/'58	Aug.3/'60	Aug.14/'59	Sep.26/59
Total rainfall mm	173,5	129	356	295
Flood discharge m^3/sec	281	315	2,701	2,078
Regulated by m^3/sec	79	62	254	352
Storage actually used for flood control m^3	620,000	610,000	2,030,000	10,160,000
(Equivalent rainfall) mm	(3)	(3)	(2)	(7)
Actual power generation KWH (year)	8,570,000 1959	8,823,000 1960	148,375,000 1959	112,092,000 1960

F: Flood control A: Irrigation
P: Power generation W: Water supply

vacancy capacity available at the time of a flood is only a few millimeters in terms of rainfall, we should say that the actual operation of reservoirs is conducted with great dexterity.

9. As regards power generation, the results obtained are near the planned figures, as is shown in the same table. This has been brought about by the intention of the administrators of the power generation projects to heighten the storage level in order to bring advantage to their power generation projects shown in terms of income. From the standpoint of flood control, the planned effect cannot be hoped

for unless the dam is vacant for the capacity necessary for flood control whenever a flood occurs. On the other hand, from the standpoint of the enterprisers of water utilization such as power generation and domestic water, it is desirable that the reservoir be one that can readily meet any demand and be operated most economically. If possible, it is desired that the storage level be always kept near the full water stage.

10. When a dam is used for two or more purposes, this conflict between the purposes is inevitable so long as their aspects of use are different. In planning a dam project, it is prerequisite to establish an operation method of the reservoir which satisfies all the enterprisers concerned. In the postwar multi-purpose dam projects, this way of thinking was developed into the idea of capacity allocation of the reservoir.

11. The multi-purpose dams built in the postwar years under integrated river development projects can be distinguished from the prewar multi-purpose dams by the establishment of the ideas of cost allocation and capacity distribution. With regard to the cost allocation, the alternative justifiable expenditure method which is now adopted in Japan is essentially connected with the problem of capacity distribution. In this sense, it may be said that the idea of capacity distribution is the most significant feature of the multi-purpose dams in postwar Japan.

III. BASIC IDEA OF CAPACITY ALLOCATION

12. Capacity allocation is the conceptually established use division of the water storage levels intended for the most rational use of water. As was stated in the preceding paragraph, the biggest defect of the river water control projects in the prewar years was in the fact that it was not clear what storages were available for the respective purposes. In view of such experiences, capacity allocation came to be adopted in the projects in the postwar days.

13. The kinds of water storages according to the present Japanese division are: the sand sedimentation capacity V_s, dead water capacity V_d, flood control capacity V_f, power generation capacity V_p, irrigation capacity V_a, industrial water capacity V , and domestic water capacity V_w, The respective storage capacity are determined as follows:

(a) Sand Sedimentation Capacity

As a rule, the amount of sand and detritus produced in the catchment area above the dam in the course of 100 years is taken in determining the capacity. In Japan the durability of dams is fixed at 80 years, so the amount to be produced in 80 years may be adopted. However, considering some factors including the difference between the design sedimentation and the actual sedimentation, we adopt the 100-year sedimentation.

(b) Dead Water Capacity

In a dam exclusively for power generation, the low water level for use of the storage water cannot be made lower than a certain limit for the reason of power generation efficiency, and so the water below the level is usually kept without being used in the form of dead water. In the case of multi-purpose dams, provision is sometimes made for dead water capacity.

(c) Flood Control Capacity

We determine the storage capacity necessary for flood control on the basis of the quantity to be cut out of the peak discharge necessitated for flood control of the lower reaches according to the imaginary design flood type at the dam site, establishing the rules of flood control taking into consideration the actual operation and flood discharging facilities. In fixing the actual flood control capacity, it is customary in this country to add a 10 - 20% allowance to the calculated flood control capacity.

(d) Power Generation Capacity

In Japan the only conflict of the storage capacity for power generation with another storage capacity occurs in summer when it conflicts

with the storage capacity for flood control. As there is no essential conflict between the capacity for power generation any other capacity, all the effective storage capacity fixed by the combination of the capacities other than the flood control capacity is utilized for power generation, and the power generation project is worked out on the basis of the supply and demand of electicity within such limit.

(e) Irrigation Capacity

The necessary storage capacity is determined on the basis of the quantities of water necessitated for irrigation of the lower reaches in the respective seasons of the year according to the established rules of discharge.

(f) Industrial Water Capacity

(g) Domestic Water Capacity

Both are determined on the basis of the imaginary need of water in the cities in the lower reaches along the river.

14. When the storage capacities for the respective purposes have been determined in these ways, the scale of the multi-purpose dam is determined on the basis of the combination of the capacities. However, if the calculation were to be the simple addition of the respective capacities, construction of the multi-purpose dam would bring no great advantage: it would be meaningless. What brings economy is to communize the storage capacity on the condition that the respective purposes can secure the minimum necessary water. Therefore, let us consider what combination of the said capacities will make the dam project most economical.

IV. COMBINATION OF STORAGE CAPACITIES FOR VARIOUS PURPOSES

15. Of the storage capacities enumerated above in (a) through (g), the capacity mentioned in (a) is always determined regardless of the capacities for the other purposes because it is necessary for ensuring the functions of the other purposes. The capacity referred to in (b) is the capacity for the water level which it is necessary to establish above the surface of the sediment in connection with the absorption of air caused by whirlpools at the time of power generation. Therefore, it will suffice for us to tackle the problem: how to minimize the total capacity by proper combination of the storage capacities given in (c) and the following items in order to achieve the most efficient use of water.

16. It is uneconomical always to keep the flood control capacity empty, and there are three conceivable remedies:—— the first is the method of ensuring the vacancy capacity by preliminarily discharging the reserved water when there is a fear of flooding; the second is the method of changing the vacancy capacity according to the respective periods during the flood season on the basis of the size and severity of the anticipated floods; the third and last is the method of controlling floods by temporarily raising the water level within the limit of not-overtopping-the-dam at the time of flooding only.

17. In Japan at present, either the first or the second method is employed when there are hydrological data properly arranged and fully analyzed. In case it is easy to purchase the fields for the site of the reservoir, the third method is also employed fairly often. The Japanese methods of securing the water level for flood control for the multi-purpose dams operated by the Ministry of Construction as of 1956 and 1961 are given in the following table, in which you will find advancement in the way of thinking.

TABLE 5.

	1956	1961	Difference	
Number of dams whose purpose includes flood control	29	31	2	
Definite limit water level only	7	4	- 3	
Definite limit water level and preliminary discharge	1	3	2	-2
Definite limit water level and surcharge	13	8	- 5	
Definite limit water level, preliminary discharge and surcharge	1	5	4	
Change of limit water level only	0	7	7	
Change of limit water level and preliminary discharge	0	1	1	4
Change of limit water level and surcharge	4	0	- 4	
Surcharge only	1	1	0	
Preliminary discharge and surcharge	2	2	0	

As is seen in the table, there are indications that the principle of definite limit water level gradually develops to be the principle of changing the limit water level according to the period so that the storage capacity may be utilized for other purposes as far as possible.

18. The reason is that the results of hydrological investigations show it is not necessary to secure a very big storage capacity in relation to the design flood during the period from the beginning of June to the middle of August and in the last ten days of October, because during these periods there are no great floods, which usually occur during the time from the latter part of August to the beginning of October. On the other hand, in the period from the beginning of June to the mid-August water is consumed in large quantities for irrigation and domestic uses. Therefore, in June and July, it is possible to fully utilize the stored water as irrigation water and domestic water by discharging it from the reservoir according to a system. Even if a flood of a smaller size occurs, the flood discharge can be kept within the limit of the drainage capacity of the channel in the lower reaches without causing practically any hindrance to the purpose of flood control. With regard to the flood control system involving preliminary discharge, the number of such type of dams which had been only 4 in 1956 increased to 115 in 1961, which shows that the preliminary discharge system is being positively adopted. This is brought about by the consolidation of hydrological data and the progress of hydrological researches. It is anticipated that this tendency will be strengthened hereafter.

19. In this way, the capacity of flood control, for which the reservoir should be kept empty, can now be utilized for other purposes of water utilization by storing water. It has also become possible to determine the lower limit of the water stage to be kept for irrigation water according to the period by calculation of the necessary storage capacities for the respective periods through analysis of the water dearths in the past. Thus the capacity of a multi-purpose dam is allocated by proper combination of the necessary limit water stage for flood control and the lower limits of water stages for irrigation and domestic water on the basis of the respective values of estimation. The procedure of actual coordination of storage capacity is shown in Fig. 1 for convenience to comprehend what was stated above.

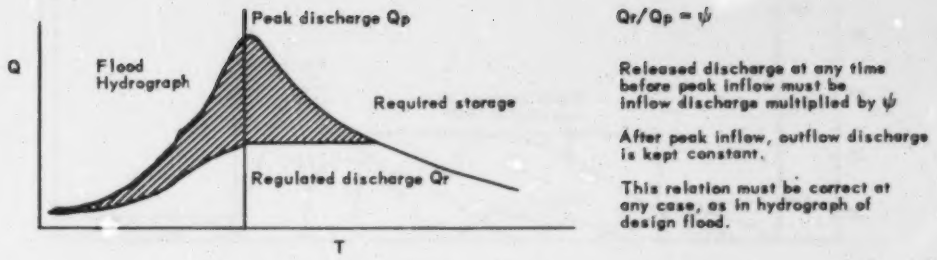
Peak discharge Qp
Q
Flood Hydrograph
Required storage
Regulated discharge Qr
T
Qr/Qp = ψ
Released discharge at any time before peak inflow must be inflow discharge multiplied by ψ
After peak inflow, outflow discharge is kept constant.
This relation must be correct at any case, as in hydrograph of design flood.

Fig. 1 - Decision of required storage for flood control

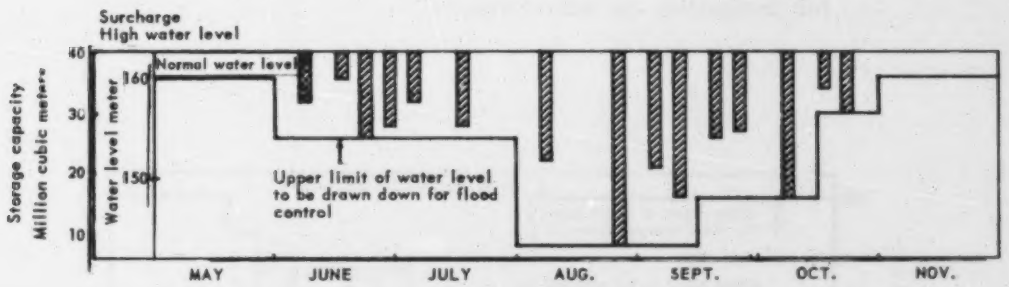

Fig. 2 - Tentative decision of seasonal water-level restriction for flood control

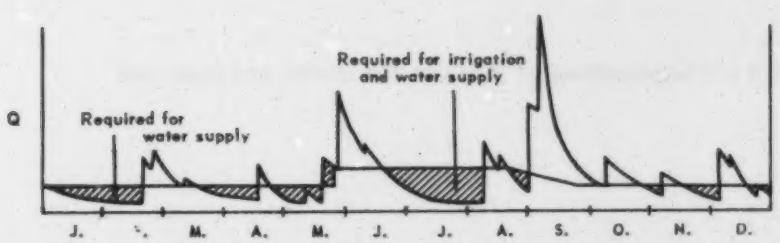

Fig. 3 - Decision of storage capacity to be secured for irrigation and water-supply

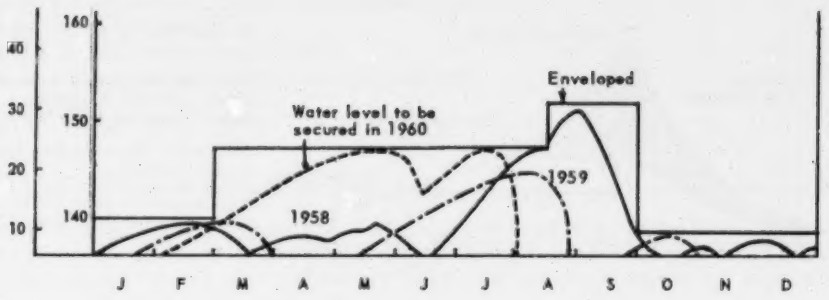

Fig. 4 - Tentative decision of seasonal water level to be secured for irrigation and water supply

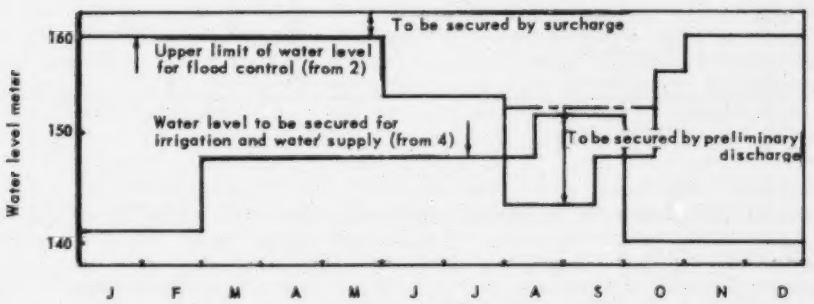
To be secured by surcharge
Upper limit of water level for flood control (from 2)
Water level to be secured for irrigation and water supply (from 4)
To be secured by preliminary discharge
Water level meter
160
150
140
J F M A M J J A S O N D

Fig. 5 - Coordination of storage for multi-purpose use

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